GEOSCIENCES OPERATIONS
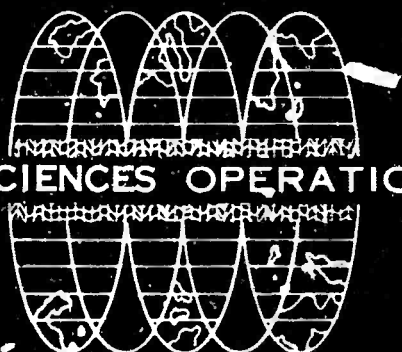
TEXAS INSTRUMENTS
INCORPORATED
SCIENCE SERVICES DIVISION
6000 LEMMON
P O BOX 56 DALLAS

CUMBERLAND PLATEAU
SEISMOLOGICAL OBSERVATORY

Quarterly Report No. 2

1 August 1965 through 31 Octob ' 1965

15 November 196 ;

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SECTION I

INTRODUCTION

Texas Instruments Incorporated has overall responsibility for operation of the Cumberland Plateau Seismological Observatory during the period of May 1965 through April 1966. The station is operated for the Air Force Technical Applications Center (AFTAC) under the sponsorship of the Advanced Research Projects Agency (ARPA) as part of the VELA UNIFORM program.

This second quarterly progress report reviews the analysis, engineering and research tasks which have been performed or initiated during August, September and October of 1965.

During this second 3-month period of the contract, routine operations and analysis have continued at CPSO. The research tasks involving ambient noise studies, signal-to-noise ratio studies and detection capability are advancing smoothly.

This report is divided into two functionalized sections (excluding the introduction); vis., Section II deals with station operations and research and Section III covers the research tasks conducted by the Dallas facility.

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SECTION II

OPERATION

A. DESCRIPTION

A general description of the station operation and instrumentation was provided in CPSO Quarterly Report No. 1. Since that time, two high-frequency instruments were installed at the station that caused the develocorder and magnetic tape recorder channel designations to change, effective 26 October 1965.

The response of these systems to constant ground motion input is shown in Figures II-1 and II-2. The revised channel designations are presented in Tables II-1 and II-2 for trace identification.

B. ANALYSIS

1. Station Analysis — Routine

A relatively complete description of the analysis performed at the station has been presented in CPSO Quarterly Report No. 1.

Analysis for the period of August, September and October of 1965 has proceeded on schedule in a normal routine manner. Signal detection, however, has sometimes been severely hampered by storm-generated noise and by develocorder malfunctions. The number of events recorded since July are as follows:

Month	Teleseisms	Near Regionals
August	319	2
September	250	0
October	308	0

2. Station Analysis — Special

As reported in CPSO Quarterly Report No. 1, two projects currently are in progress. An event library is being compiled and a study of quarry blasts is being conducted.
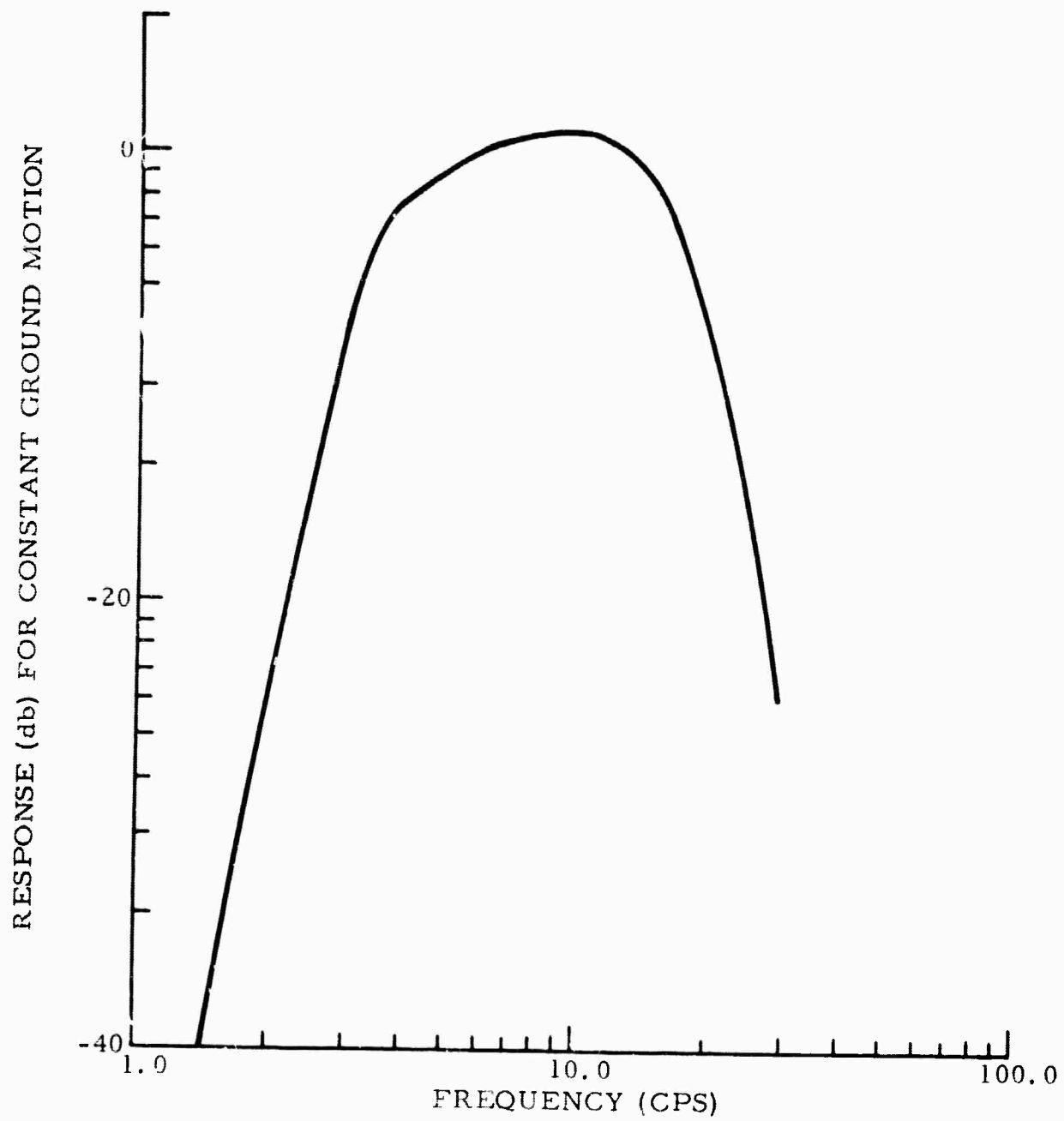
Figure II-1. Frequency Response for the ZHF5 System
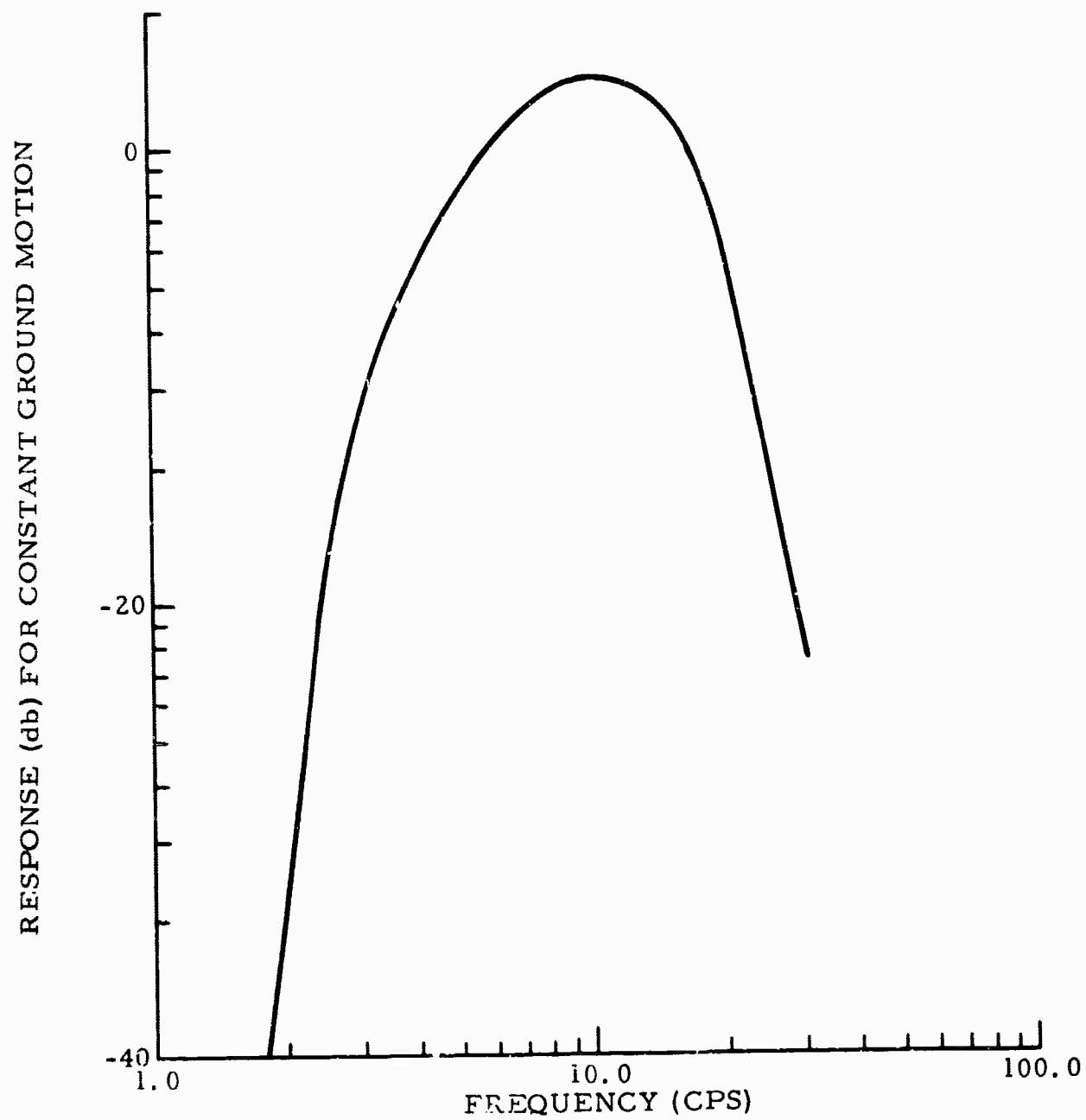
Figure II-2.   Frequency Response for the ZHF6 System

Table II-1

DEVELOCORDER TRACE ASSIGNMENTS

Channel Number	Short Period Primary Data	Short-Period Secondary Data	Long-Period Primary Data
1	V (earth-powered Benioff)	V (earth-powered Benioff)	WI (anemometer)
2	Z 7	Z8L	MS (uncalibrated SP microbarograph)
3	Z 1	Z8	LPZ (low gain)
4	Z 4	Σ 11, 12, 13	LPN (low gain)
5	Z 2	Σ 1, 7, 17, 18	LPE (low gain)
6	Z 3	Σ 4, 7, 17, 19	LPZ (high gain)
7	Z 5	Σ 1, 4, 7, 17, 18, 19	LPN (high gain)
8	Z 6	Σ 3, 6, 9, 14, 15, 16	LPE (high gain)
9	Z 9	Σ 1, 3, 4, 6, 7, 9, 10, 14, 15, 16	ML (uncalibrated LP microbarograph)
10	Σ 10-19	MS (uncalibrated SP microbarograph)	Z8
11	Σ TF (filtered 1-19)	WI	WWV
12	Σ T (1-19)	ZHF5 -30db	——
13	Z 8	ZHF5 -50db	——
14	SPN	ZHF6 -30db	——
15	SPE	ZHF6 -50db	——
16	WWV	WWV	——

Table II-2

TAPE RECORDER TRACE ASSIGNMENTS

Channel Number	Tape Recorder No. 1	Tape Recorder No. 2
1	TCDMG (Time Code)	TCDMG (Time Code)
2	Z 1	LPZ (high gain)
3	Z 2	LPN (high gain)
4	Z 3	LPE (high gain)
5	Z 4	SPN
6	Z 5	SPE
7	Compensation	Compensation
8	Z 6	ZHF5 -10db
9	Z 7	ZHF5 -30db
10	Z 8	ZHF5 -50db
11	Z 9	ZHF6 -10db
12	Z10	ZHF6 -30db
13	Σ TF (1-19 filtered)	ZHF6 -50db
14	WWV and Voice	WWV and Voice

The compilation of the station event library is progressing smoothly. Generally, the library is composed of indexed reproductions of interesting or unusual events taken from film data. In addition, each event is cross-indexed as to computed and published phase-location, magnitude and travel times.

The quarry blast study will make possible the construction of accurate travel-time curves for local, near regional and regional events recorded at CPSO. To date, approximately 100 quarry blasts have been analyzed to locate prospective sites for recording origin or shot times. Recording equipment for use in this study currently is being assimilated and tested for operation.

In conjunction with this study, computation of apparent horizontal velocity is being made to investigate possible correlation with azimuth and distance.

C. ENGINEERING

1. Instrumentation

The overall quality of the instrumentation has been improved since July 1965, resulting in better data quality. A large contributor to this improvement has been the installation of lightning protectors, Associated Electrical Industries Model 16. Since installation of the new protectors in August and September, CPSO has not experienced any instrument change or down time due to electrical storms. Other factors contributing to better instrument quality has been the development of a preventive maintenance program and standard procedures for instrument operation for this station.

Some problems experienced during the period of August, September and October of 1965 were

- Develocorder malfunctions due to severe corrosion caused by photographic chemicals. This is a continuing problem and can be remedied only by develocorder replacement

- Tape recorder spikes and dropouts caused by worn tape guides, faulty signal discriminators and noisy, old tapes

- Date timer, power amplifiers and power control unit malfunctions caused by aging components

- Diminishing gain of LPZ. This problem currently is being investigated

2. Recommendations

The instrumentation can be upgraded with adequate replacement spares which will allow station personnel to substitute spares while the original unit is being overhauled. This is especially true of the develocorders, signal discriminators and date timer.

It also is recommended that some type of electrical generator be installed for use during a power failure. At present, when the station is operated on secondary or battery power, data is recorded only on film and not on magnetic tape. With an automatic electric generator to drive the tape recorders and helicorders, data can be recorded on all systems.

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D. QUALITY CONTROL

A detailed description of the quality control procedures for the CPSO data was presented in Quarterly Report No. 1. The overall quality of the film data has been good. However, as pointed out in subsection C. 1, the develocorder data does contain stops and skips. The quality of the magnetic tape data has been good except for the problem of old and worn tapes.

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SECTION III

RESEARCH

A. GENERAL

The research activity conducted under this contract is, in general, proceeding on schedule. The ambient noise studies have progressed sufficiently to indicate that the noise field is running relatively constant when compared with data collected in 1963. On the basis of this preliminary conclusion, initial multichannel filter development has begun.

As of this report date, sufficient results have not been obtained to warrant discussion of the signal-to-noise ratio studies and detection capability studies.

B. AMBIENT NOISE STUDIES

1. Power Density Spectra

The single-channel absolute power-density spectra have been computed, as proposed in Quarterly Report No. 1, on a daily basis for May, June and July of 1965. Figure III-1 shows six representative power-density spectra computed from the July data. These spectra for July have been studied and compared with previously computed power-density spectra. Very little change can be noticed in the general noise level or shape of these spectra. However, slight changes in power can be observed for individual frequencies.

In Quarterly Report No. 1, attention was given to the fluctuating peaks in the power-density spectra at the well-defined frequencies of 0. 50, 1.40, 1. 90, and 2. 90 cps. For each of the defined frequencies, an attempt was made with the existing data to correlate the fluctuation of power with time. Efforts to relate the variation in power with the time of day proved unsatisfactory, since the different hours of the day had to be taken from data extending over the period of a month. As more data is processed, the variation over longer periods will be studied. Also, noise samples will be taken from each hour for a continuous 48-hr period to study any short time fluctuations.
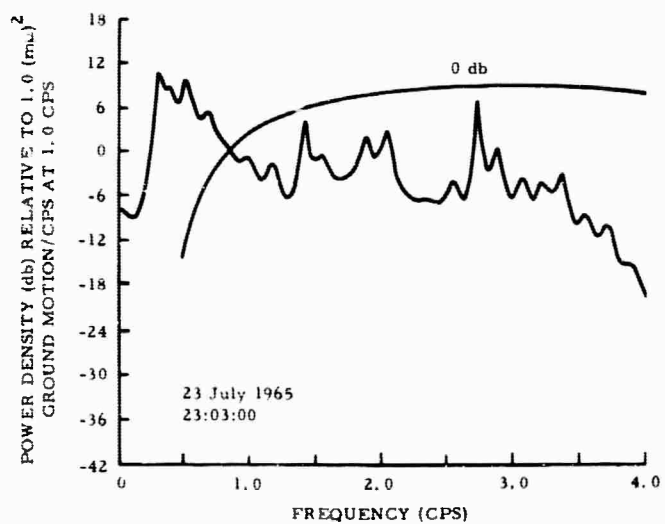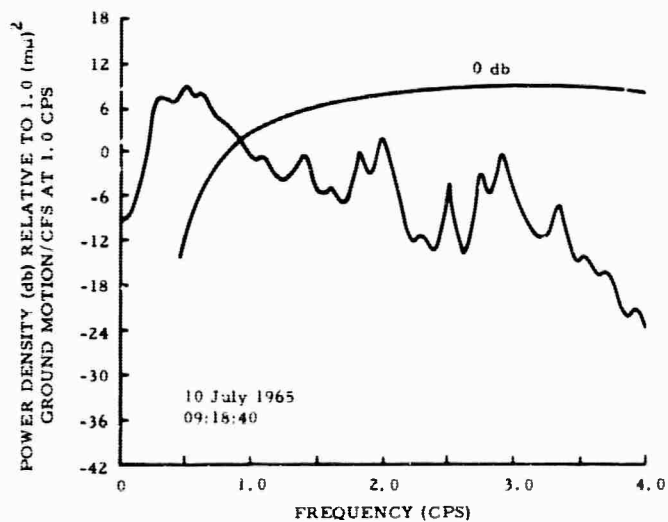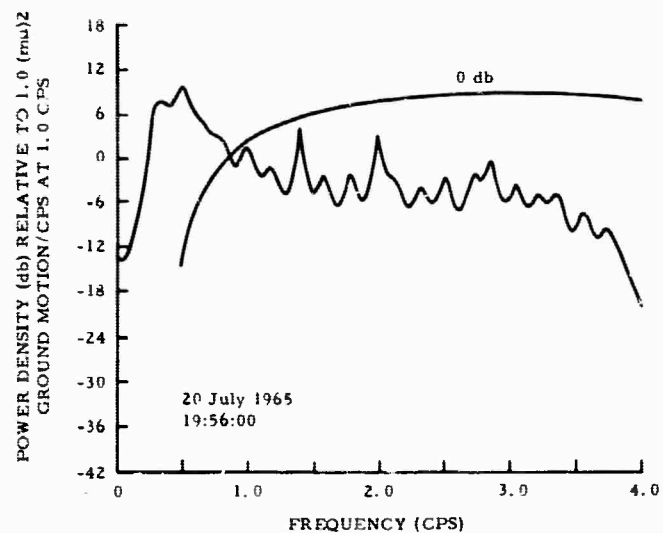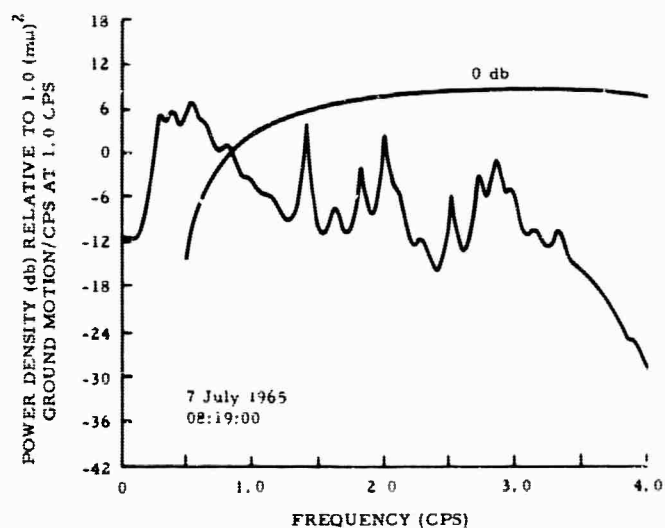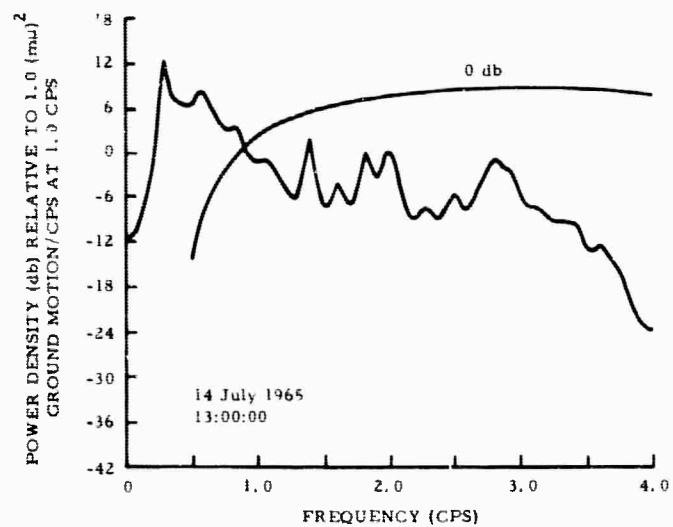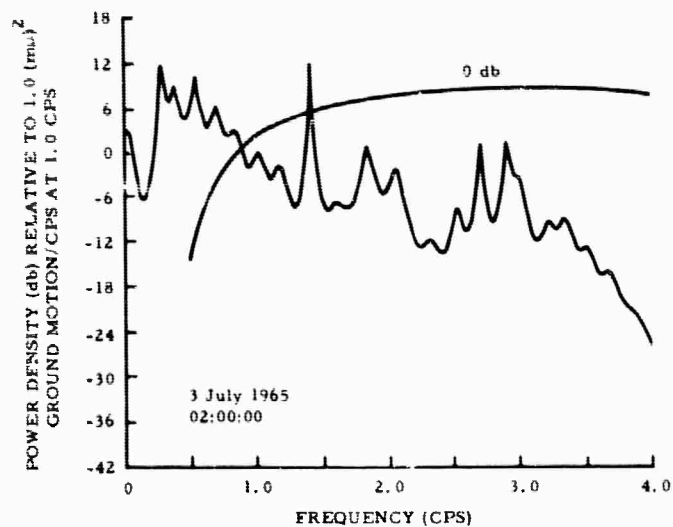
Figure III-1. CPSO Ambient Noise Power-Density Spectra
for July 1965

The variation in the power level at other frequencies also was studied. Results showed an expected relation with time of day, thus, indicating a possibility that a portion of the noise power was due to cultural activity. This variation for frequencies of 1.0, 1.5, 2.0, and 2.5 cps is displayed in Figure III-2. At each frequency, the noise power appears highest between approximately 8 a.m. and 6 p.n , the period of greatest cultural activity.

An attempt to relate changes in the power-density spectra with daily or seasonal changes was unsuccessful, as indicated in Figure III-3. The variation appears random and will require further data to determine any long time changes.

2. Frequency-Wavenumber Spectra

Seven frequency-wavenumber spectral estimates were computed from data recorded during July for the frequencies of 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.25, and 2.50 cps. The noise data was · selected at various hours from the days of July 3, 7, 10, 14, 17, 20, and 23.

Frequency-wavenumber spectra for the frequencies of 1.00 and 1.75 cps from two of the noise samples, July 3 and July 14, are shown in Figures III-4 through III-7.

The frequency-wavenumber spectra for July, in general, agree with the previously presented spectra for May and June 1965 and with the 1963 average. At frequencies of 1.0 cps and below, the spatially organized noise field is essentially the same as other spectra computed for the CPSO ambient noise field, indicating that the low-frequency (0.5 to 1.0 cps) noise field is remaining relatively stable.

The spectra at 1.75 cps show several spatially organized noise lobes. A fluctuation in power of individual lobes is apparent at this frequency. First observations indicate that lobe 3 and possibly lobe 6 fluctuate most significantly. Efforts still are being made to correlate this power fluctuation of specific lobes with the possible generating sources. A study of the local area and the activities capable of generating the existing noise lobes should help to verify that the energy of a specific noise lobe is fluctuat   The significance of the variation in power will be studied in future an .ysis.
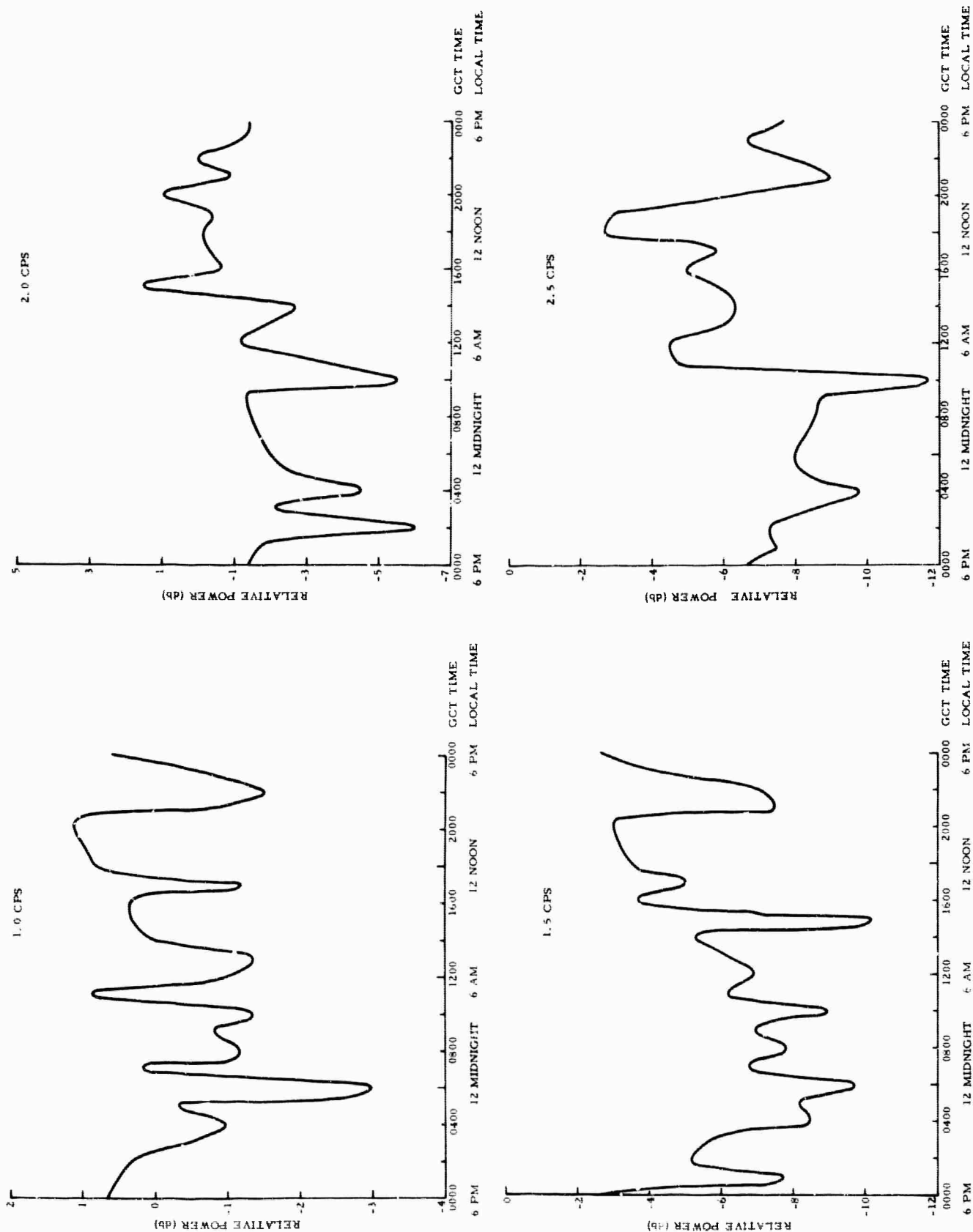
Figure III-2. Power Variation vs Time of Day
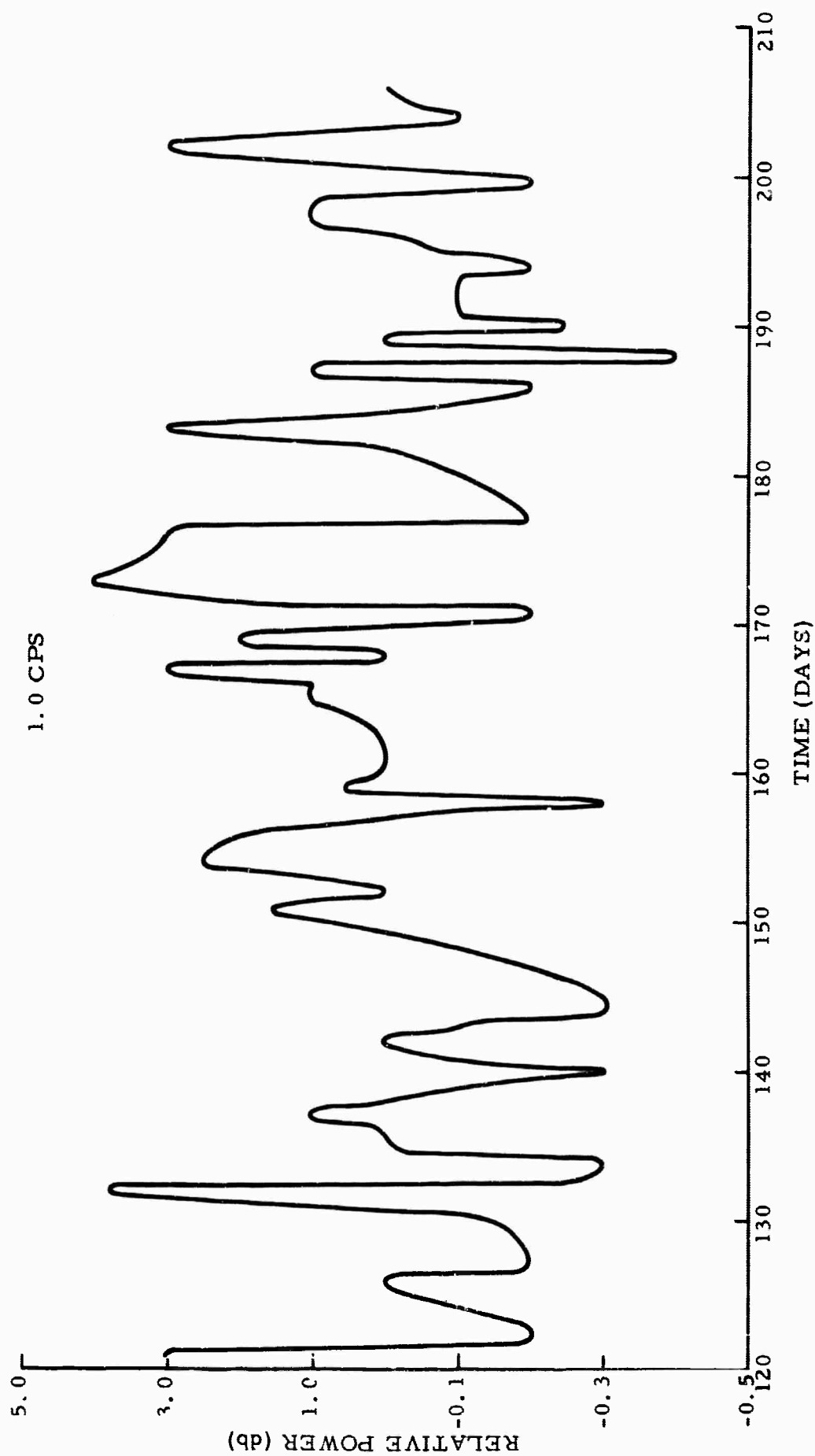
Figure III-3. Power Variation Over a Period of Three Months

Figure III-4. CPSO Ambient Noise Frequency-Wavenumber
Spectrum, July 3, 1965 (f = 1.00 CPS)

Figure III-5.   CPSO Ambient Noise Frequency-Wavenumber
Spectrum, July 3, 1965 (f = 1.75 CPS)

Figure III-6. CPSO Ambient Noise Frequency-Wavenumber
Spectrum, July 14, 1965 (f = 1.00 CPS)

Figure III-7. CPSO Ambient Noise Frequency-Wavenumber
Spectrum, July 14, 1965 (f = 1.75 CPS)

An effort is being made to correlate the organized noise lobes with their source. If the lobes can be associated with a source, this will result in almost complete description of the lobe since the source probably may be described. Coordination with station personnel presently is being maintained with respect to this effort.

3. Prediction Filtering Results

Spatial prediction filters have been developed from data recorded on May 4, June 2 and July 3, 1965. These filters have been applied to their respective data samples from which they were designed and the results were analyzed.

The percentage of spatially predictable noise power for the three filters is shown in Figure III-8. Frequencies above 2.0 cps indicate very little predictability with the array geometry used in this study. Previous studies have shown a higher degree of predictability at CPSO using a 19-element array which has a closer spacing of 0.3 km as opposed to 0.6 km for the 10-element array. With the 10-element array, it appears that noise at frequencies above 2 0 cps cannot be studied properly in the frequency-wavenumber spectra.

Small variations are observed in the percentage of spatially predictable noise power, especially around the frequencies of 0.25 and 1.00 cps. Comparing these changes in the percentage of predictable noise power at 0.25 cps with the corresponding frequency-wavenumber spectra and the single-channel power-density spectra indicates that the spatially organized noise lobe 1 originating from the Southeast can be clearly related to the change. The percentage of predictability is higher when this coherent noise is higher.

Comparison of the variation around 1.0 cps with the frequency-wavenumber at 1.0 cps did not reveal a relation between the two. The single-channel power density spectra show the May and June Data have comparable power levels around 1.0 cps and the July data has a slightly higher level. This indicates a higher random noise level for the July data. A better understanding of these variations can be obtained as more data is processed and studied.

The fluctuating noise power at 1.4 cps also should be noticed on the basis of predictability. The fluctuating power appears to be completely predictable, since an increase in the power density spectra can be related directly to an equal increase in the percentage of predictable noise power at 1.4 cps.
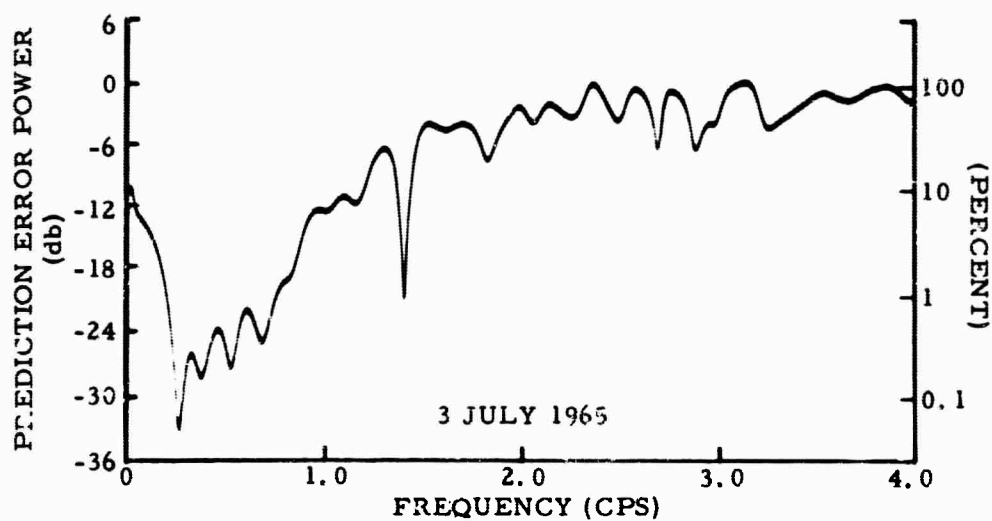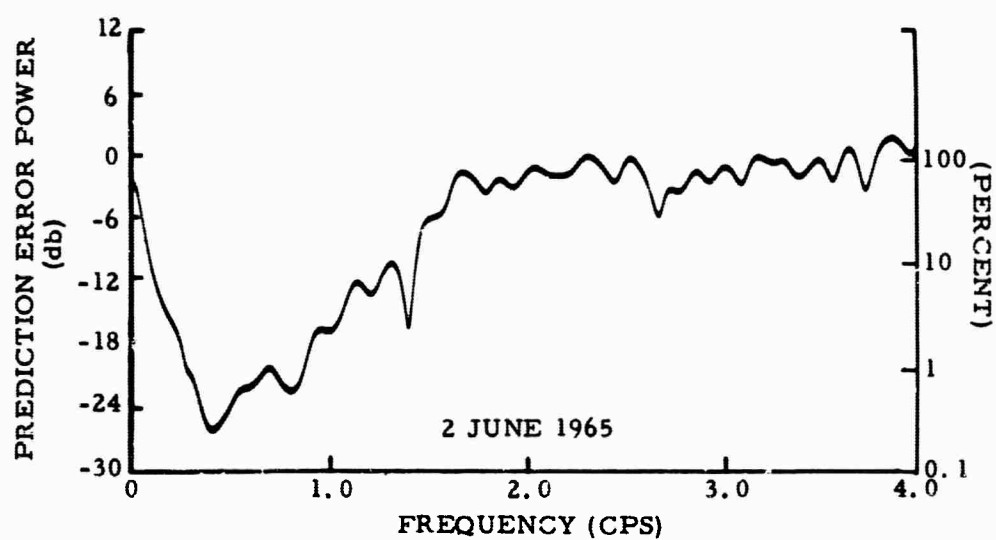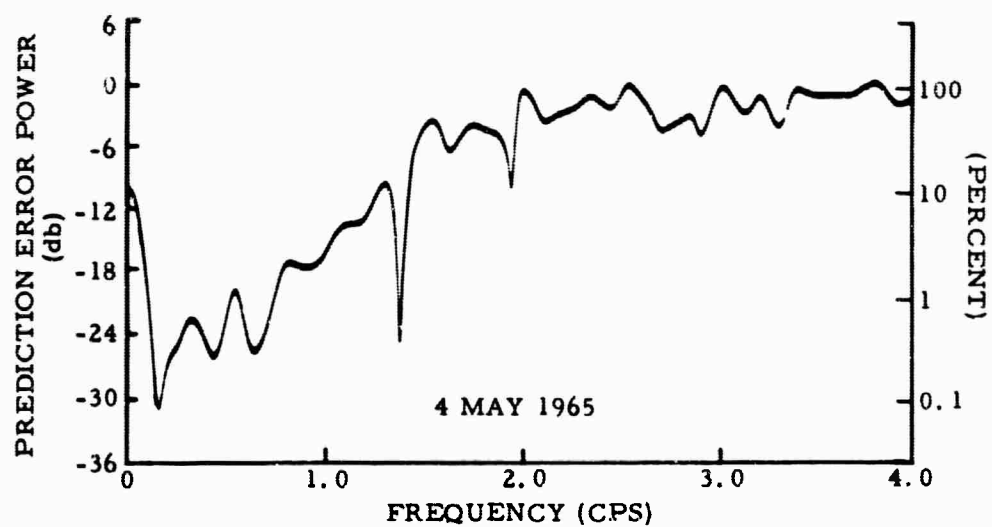
Figure III-8.   Percent Prediction Error for Three
CPSO Noise Samples

C. DEVELOPMENT OF CPSO DISPERSION DATA

Dispersion is defined by Richter as "the increase in velocity of observed surface waves with wavelength."[*] He also points out that "if the distribution of S velocity with depth differs in two regions, one should get different dispersion curves by plotting wave velocity against period."[**] This leads to the assumption that, if the crustal model is divided into distinct layers, then a curve of velocity vs frequency should exist for each wave traveling in each layer.

The dispersion curves mentioned in this section were calculated using Haskell's method.[***] To plot a dispersion curve using this technique, it is necessary to know both the depth of each layer and the velocity of the P- and S-waves in these layers. It should be noted that only the curves for the Rayleigh (LR) waves and S-waves are shown on a dispersion curve.

To determine the P, S and LR velocities for the CPSO station, fo " quarry blasts from 1963 were chosen. By observing the sequence of arrival of the waves at the different seismometers, it was possible to determine the direction of propagation of the waves across the array and the distance each wave traveled from seismometer to seismometer. Then, by measuring the time of arrival of the waves at each seismometer, the wave velocities across the array were calculated. The velocities for the different waves are shown in Table III-1. Analysis of Table III-1 shows three groups of P velocities, two groups of S velocities and one group of LR velocities. These velocities are shown in Table III-2.

Since three velocities for the P-wave are apparent, the assumption is that three distinct layers exist in the crustal model. The two deepest layers have been shown to correspond with the Conrad and Mohorovičić discontinuities. These layers are at depths of approximately 20 km and 36 km.[****]

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[*] Richter, Charles F., 1958: Elementary Seismology, W.H. Freeman and Company, San Francisco, p. 243.

[**] Ibid, p. 265.

[***] Haskell, N.A., 1953. The dispersion of surface waves in multilayered media: Bulletin of the Seismological Society of America, v. 43, p. 17-34.

[****] Foreman, Joe, 1964: Texas Instruments Incorporated, Internal Rpt., Unpub.

Table III-1

WAVE VELOCITIES

P Velocities	S Velocities	LR Velocities			
8.34	3.52	3.30	3.04	2.90	2.60
8.31	3.50	3.30	3.01	2.90	2.60
7.65	3.50	3.29	2.99	2.89	2.56
6.17	3.34	3.26	2.98	2.80	2.51
6.17	3.29	3.20	2.96	2.71	2.50
6.05	3.24	3.10	2.95	2.65	
5.01	3.12	3.07	2.90	2.60	
4.92					

Table III-2

GROUPS OF WAVE VELOCITIES

P Velocities	S Velocities	LR Velocities
8.10	3.51	2.92
6.10	3.25	
5.00		

To find the depth of the first layer, a group of dispersion curves were calculated using the Haskell method with the velocities in Table III-2 and the 20- and 30-km depths, but with different depths for the top layer. To determine which of the curves was correct, several sets of f-k spectra were studied. The velocities for the different power lobes (0 and -3 db) from these spectra then were plotted vs frequency and the resulting curve matched most closely with the curve calculated for a depth of 4 km for the top layer. This dispersion curve is shown in Figure III-9.

D. MULTICHANNEL FILTER DEVELOPMENT

Presently, two 19-channel multichannel filters are being developed and will be evaluated using 1963 recorded ambient noise and signal data. The e two systems are
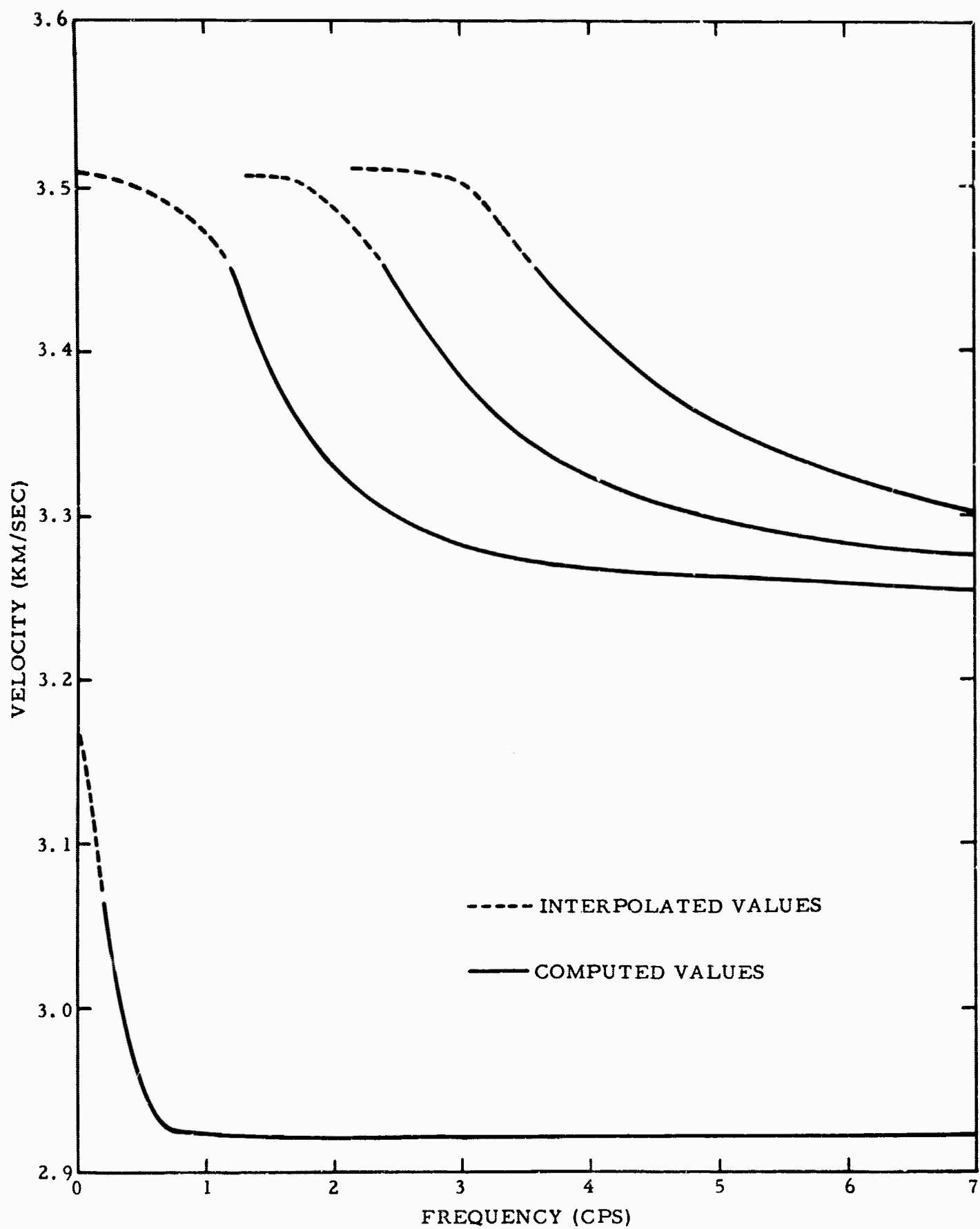
Figure III-9. CPSO Dispersion Curves

(1) A 19-channel filter developed using measured-noise correlation statistics. Signal will be defined to propagate with infinite apparent horizontal velocity. This filter will be designated CPSO MCF-1.

(2) A 19-channel filter developed using a theoretical noise model designed on the dispersion data in Figure III-9. Signal will be defined to propagate with infinite apparent horizontal velocity. This filter will be designated CPSO IP-20.

The results obtained using these two systems will be compared with previous results obtained at CPSO in order to determine improvement available with the 19-channel time-domain-developed filters. It should be noted that previous filters were developed either in the frequency domain or on ring model data.

The results obtained from MCF-1 and IP-20 will be compared to determine the accuracy of the noise model and space stationarity of the noise field.

Information obtained from this proposed analysis will be used in recommending additional filters for the on-line digital processor and will indicate the type filters which should be developed for use in the directional detection studies.